ETH zürich

High throughput generation of aircraft-like soot:

Dynamics of soot surface growth and agglomeration by enclosed spray combustion of jet fuel

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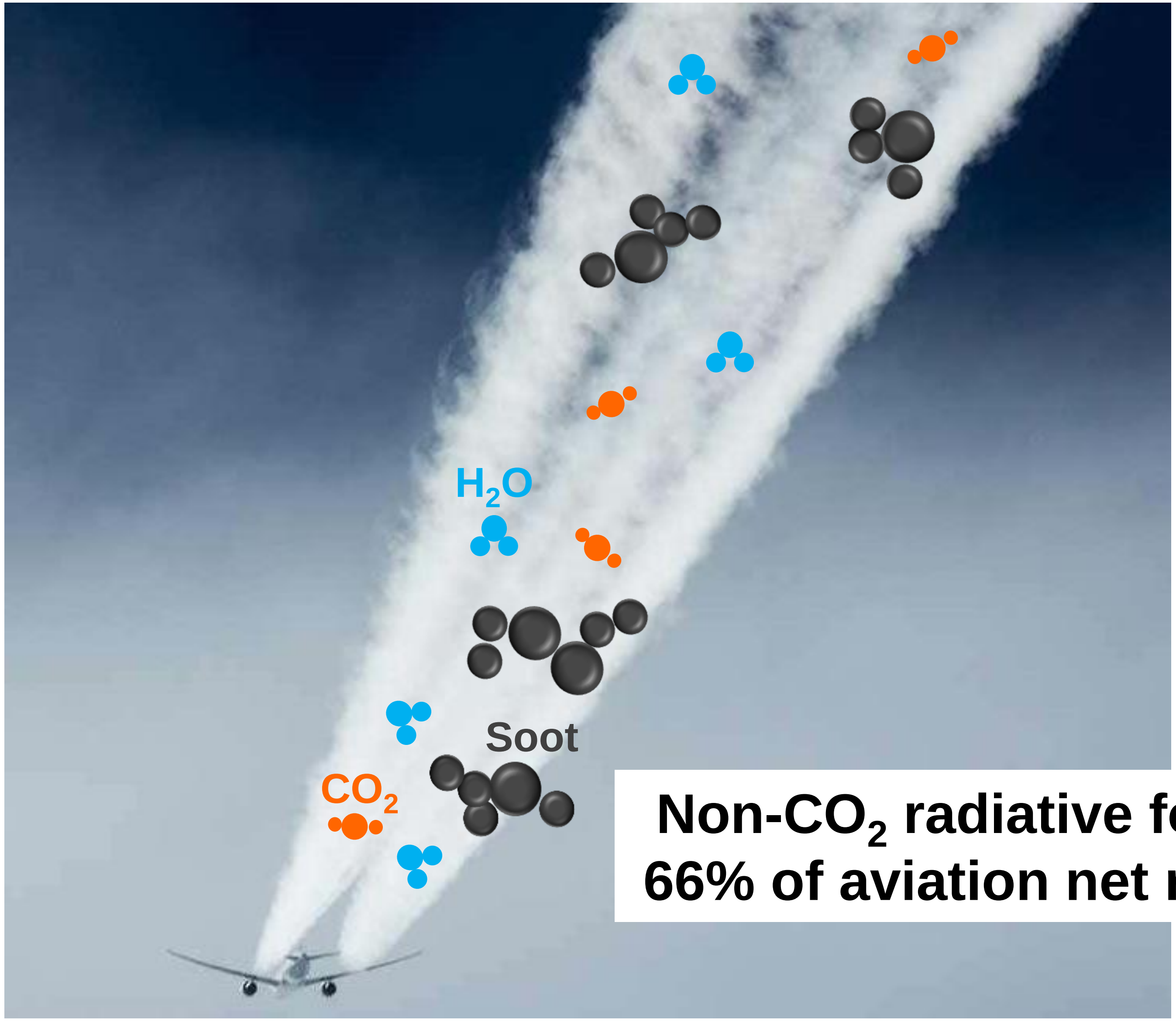
PTL Particle Technology Laboratory

FNSNF Fonds national suisse Schweizerischer Nationalfonds Fondo nazionale svizzero Swiss National Science Foundation

Aircraft emissions



Ultrafine (< 100 nm) particle air pollution [2]

Non-CO_2 radiative forcing accounts for 66% of aviation net radiative forcing! [1]

[1] Lee, D.S. et al. The contribution of global aviation to anthropogenic climate forcking for 2000 – 2018 (2021) *Atmos. Environ.* 244. 117834
[2] D. Westerdahl, S.A. Fruin, P.L. Fine, C. Sioutas (2008) *Atmos. Environ.* 42, 3143–3155.

Soot
Commercial Soot Generator

This work, enclosed spray flames:

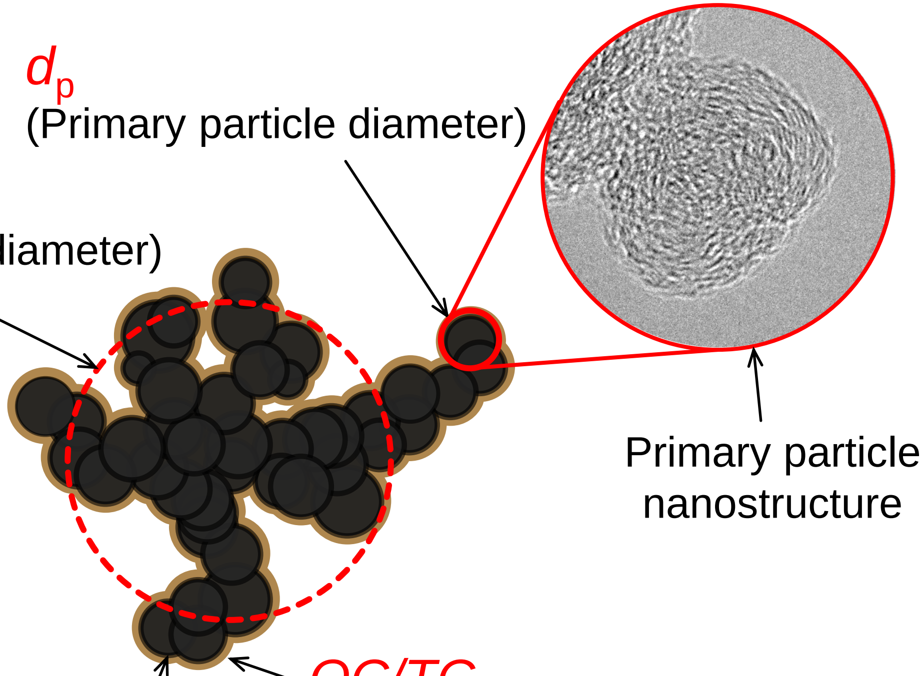
Aircraft-like with high throughput

MiniCAST:

Cannot produce high-thrust aircraft soot (OC/TC too high or d_m too large)

d_p (Primary particle diameter)

d_m (Mobility diameter)



Primary particle nanostructure

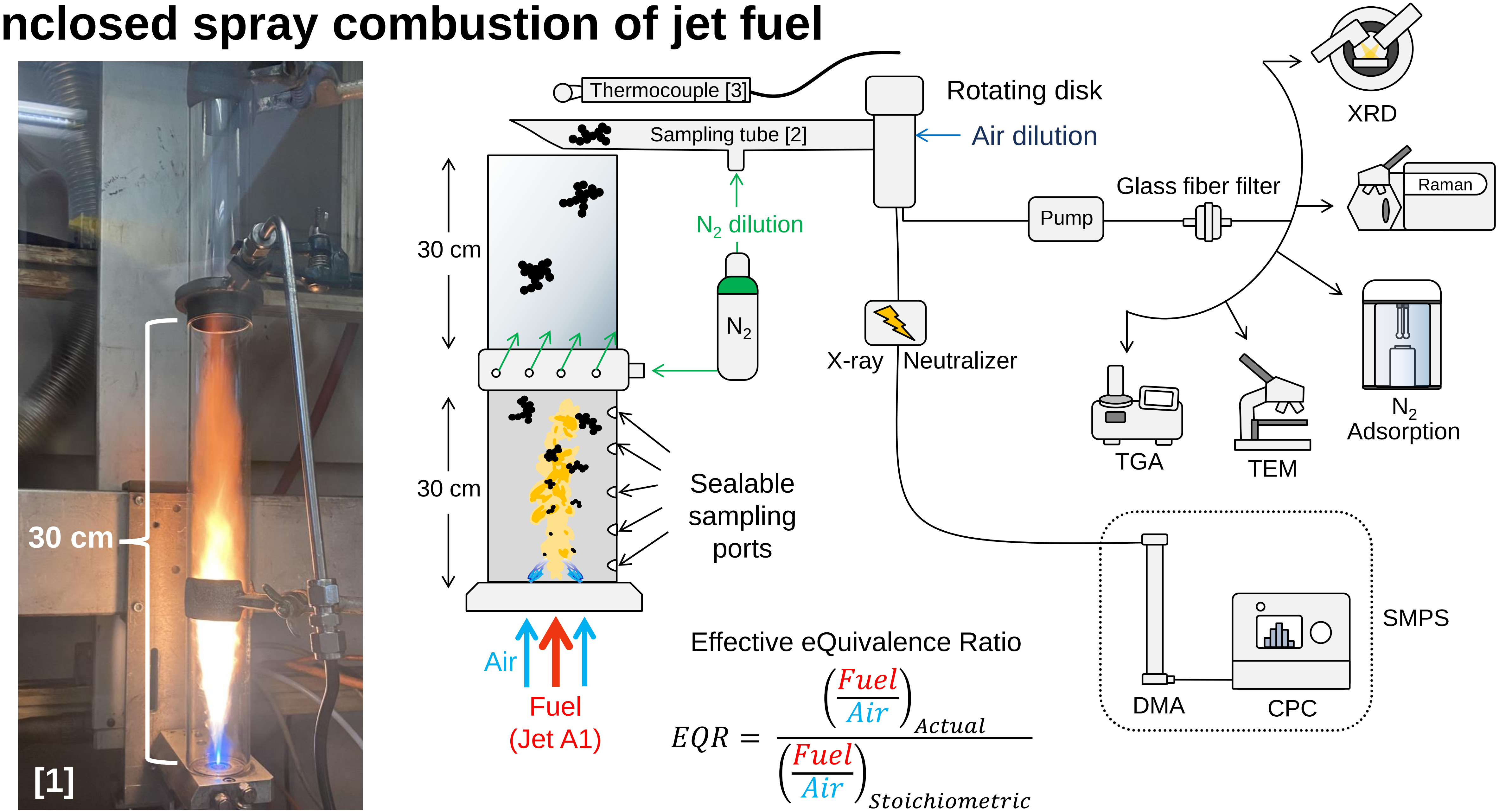
OC/TC (Organic carbon to total carbon)

SSA (Specific Surface Area)

SSA measurements require 10s of mg of soot!

[1] U. Trivanovic, G.K. Kelesidis, S.E. Pratsinis (2022) *Aerosol Sci. Technol.* 56, 732-743.

Enclosed spray combustion of jet fuel

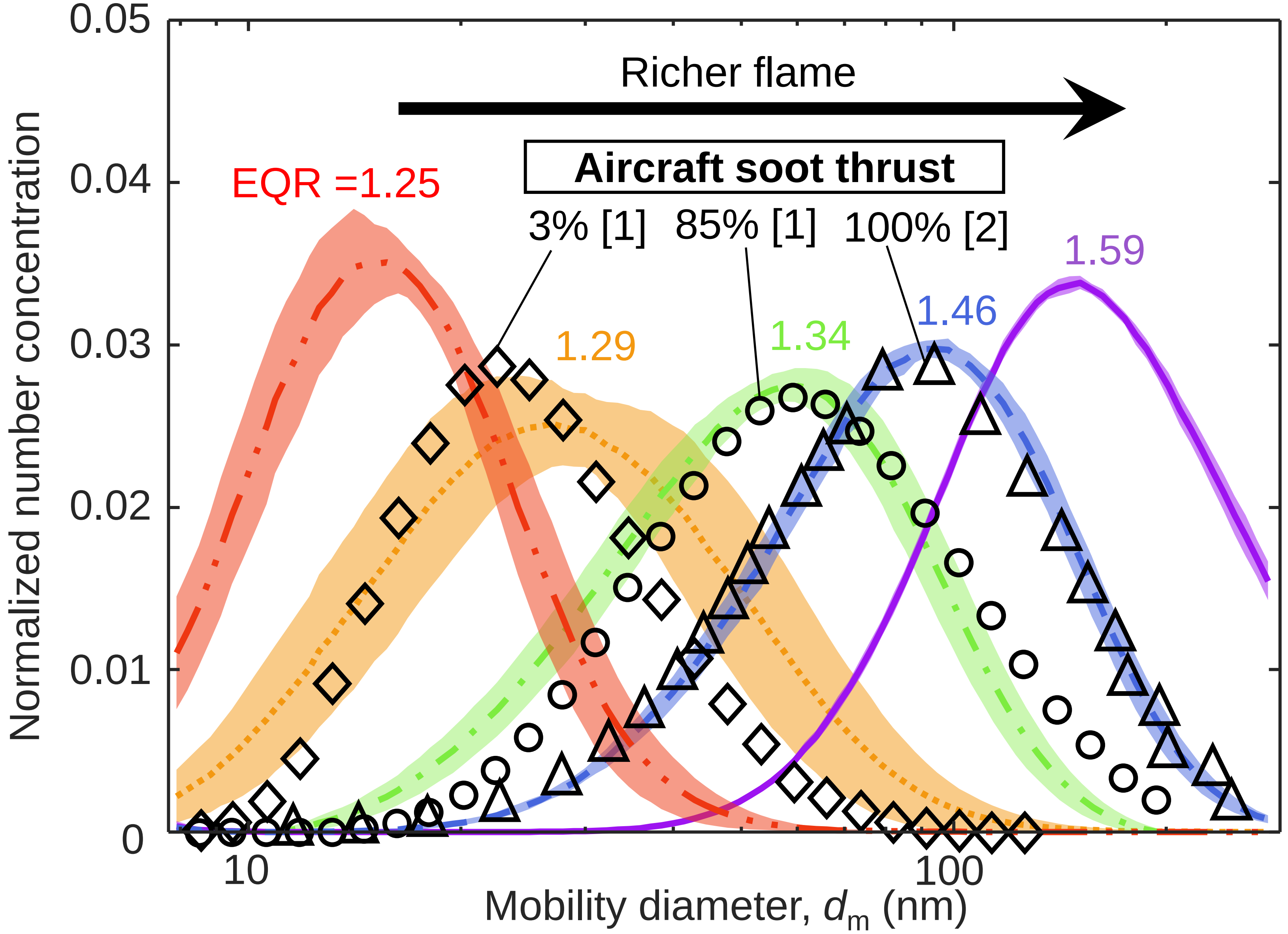


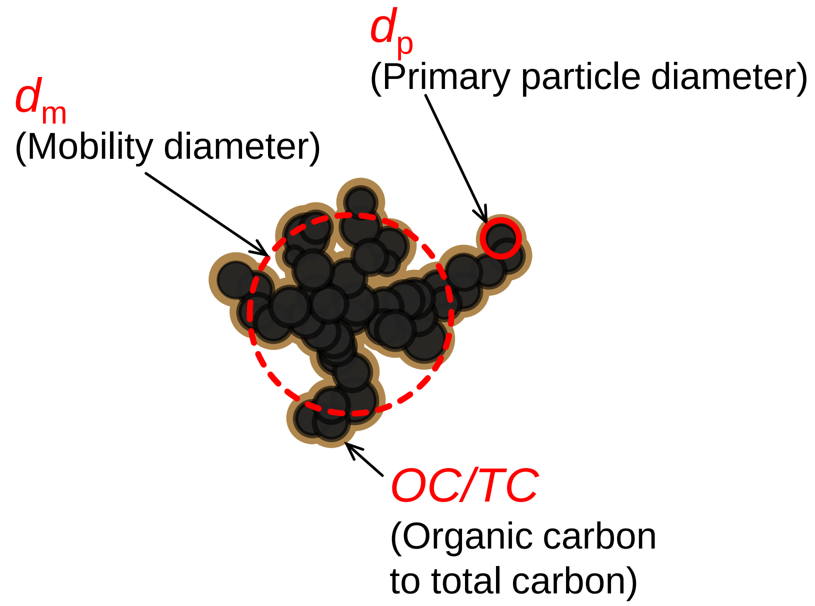
Effective eQuivalence Ratio

$$EQR = \frac{\left(\frac{Fuel}{Air}\right)_{Actual}}{\left(\frac{Fuel}{Air}\right)_{Stoichiometric}}$$

[1] U. Trivanovic, G.K. Kelesidis, S.E. Pratsinis (2022) *Aerosol Sci. Technol.* 56, 732-743.
[2] E. Goudeli, A. J. Gröhn, S.E. Pratsinis. (2016) *Aerosol Sci. Technol.* 50, 591-604.
[3] U. Trivanovic, M. Pereira Martins, S. Benz, G.A. Kelesidis, S.E. Pratsinis (2023) *Fuel.* 342, 127864.

Characteristics of enclosed spray combustion (ESC) soot





ESC soot $\bar{d}_p$ ~ 14 nm

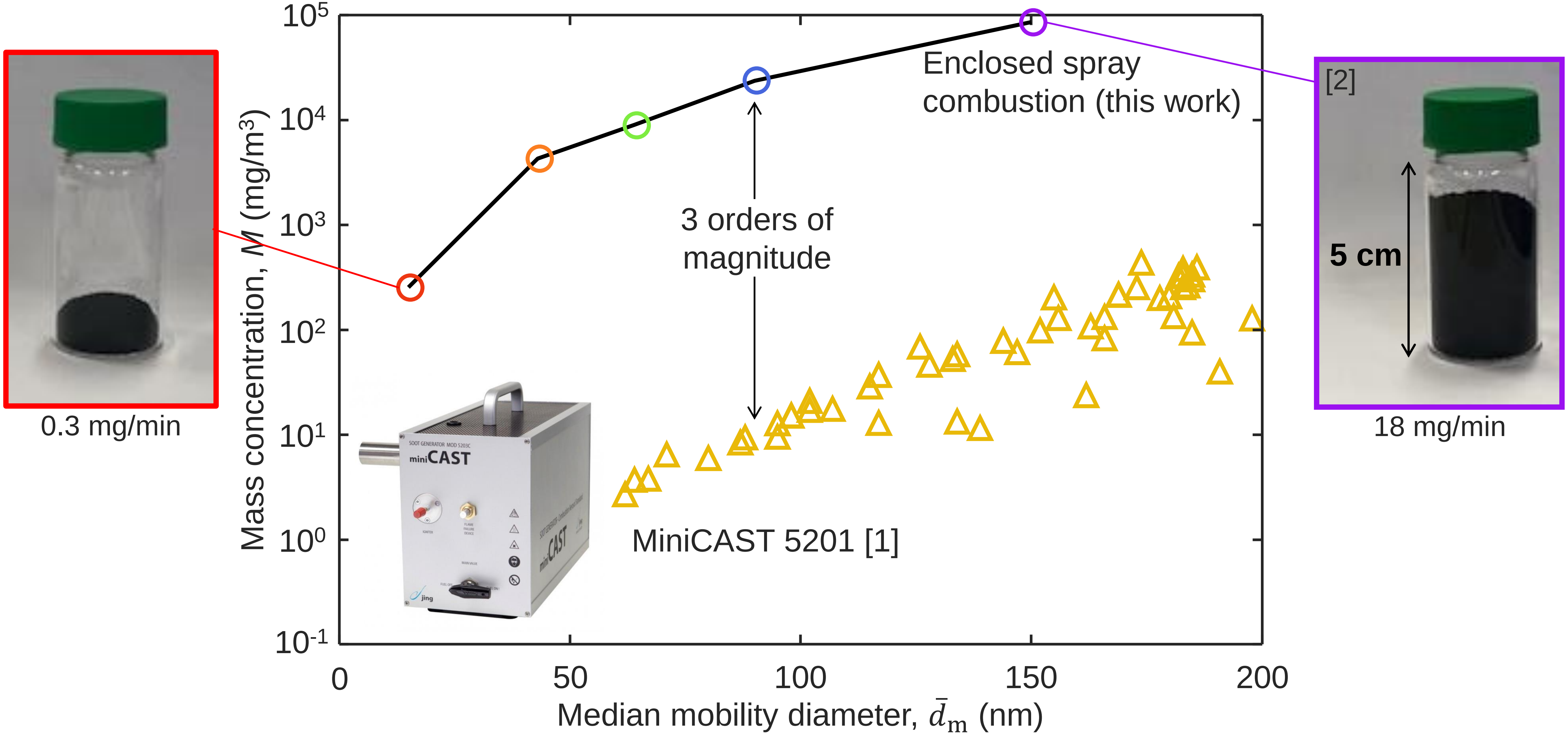
Aircraft soot $\bar{d}_p$ from 10 – 20 nm [3]

ESC soot 10% < OC/TC < 20%

High thrust aircraft soot *OC/TC* < 25% [2]

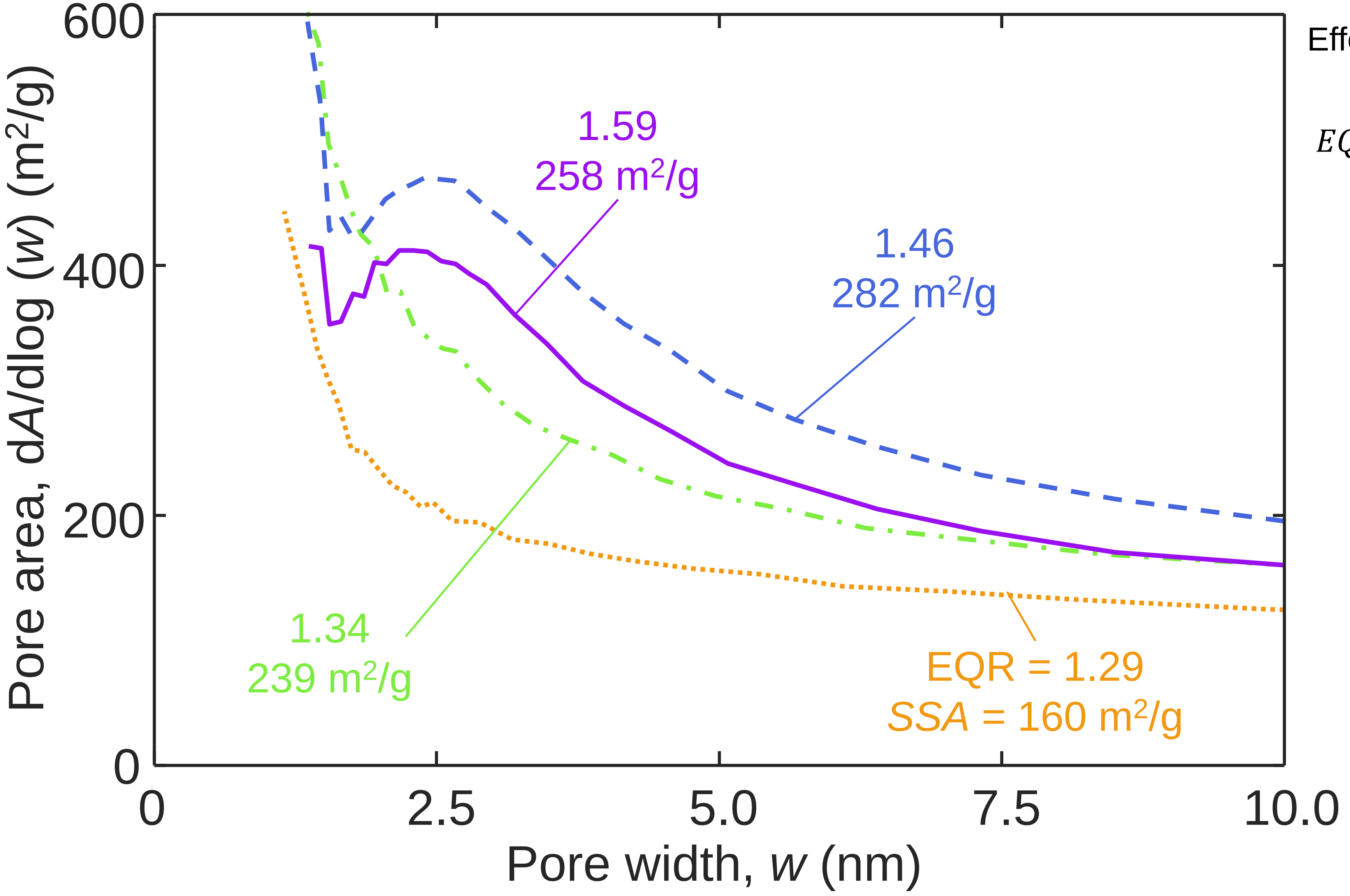
[1] M. Abegglen, L. Durdina, B.T. Brem, J. Wang, T. Rindlisbacher, J.C. Corbin, U. Lohmann, B. Sierau (2015) *J. Aerosol Sci.* 88, 135 – 147.
[2] D. Delhaye, F.-X. Ouf, D. Ferry, I.K. Ortega, O. Penanhoat, S. Peillon, F. Salm, X. Vancassel, C. Focsa, C. Irimiea, et al. (2017) *J. Aerosol Sci.* 105, 48 – 63.
[3] A. Liati, B.T. Brem, L. Durdina, M. Vögtli, Y.A.R. Dasilva, P.D. Eggenschwiler, J. Wang (2014) *Environ. Sci. Technol. 48*, 10975 – 10983.

Mass concentration



[1] M. Ess & K. Vasilatou (2019) *Aerosol Sci. Technol.* 53, 29 – 44.
[2] U. Trivanovic, G.K. Kelesidis, S.E. Pratsinis (2022) *Aerosol Sci. Technol.* 56, 732-743.

Pore size distributions & Specific Surface Area (*SSA*)



Effective eQuivalence Ratio:

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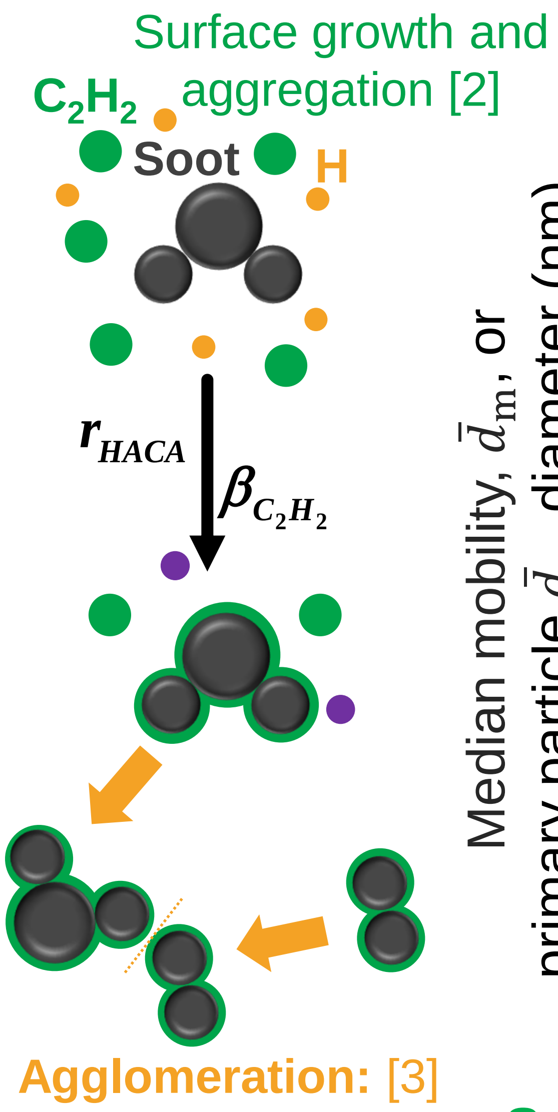
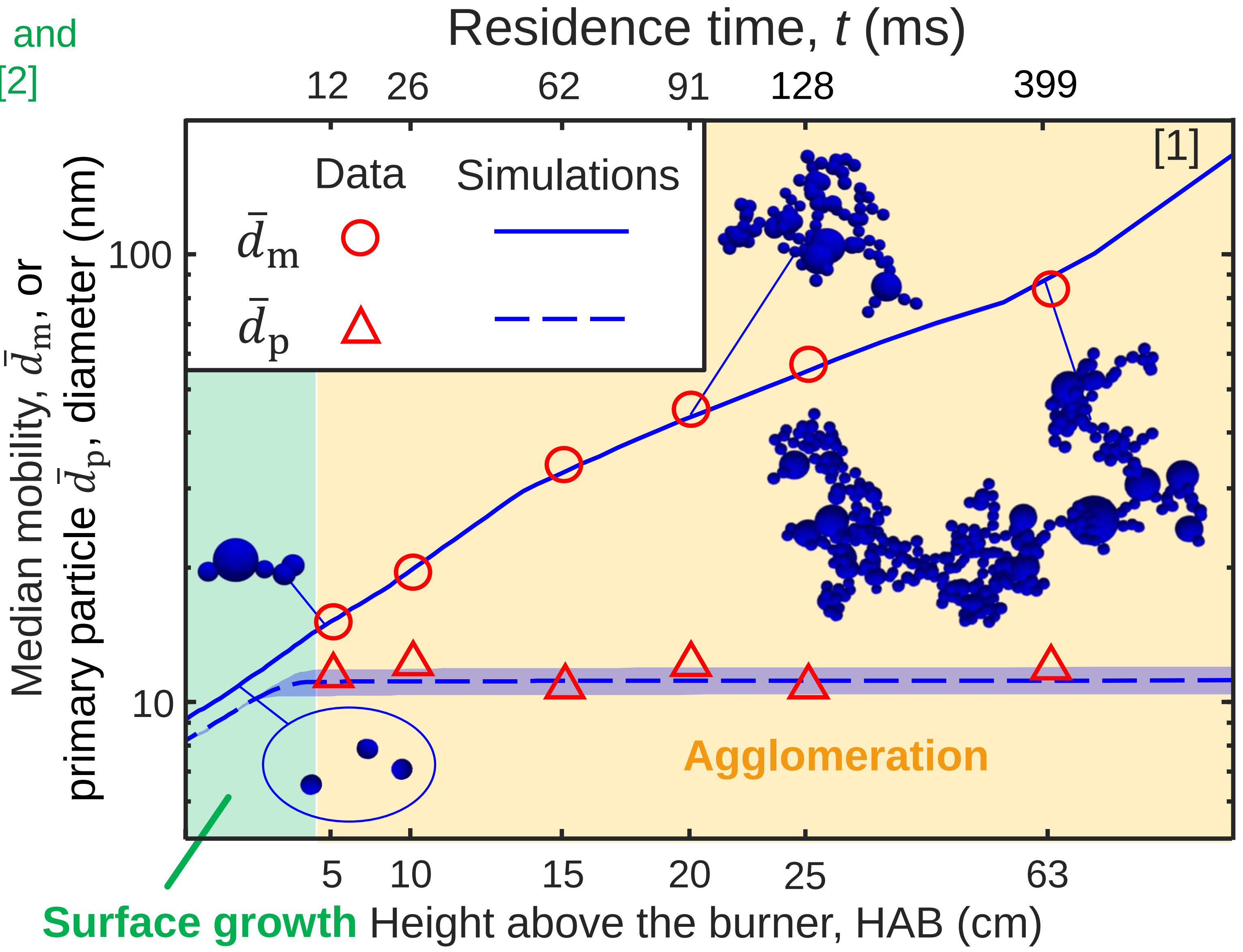
Evolution of mobility and primary particle diameter (EQR = 1.46)





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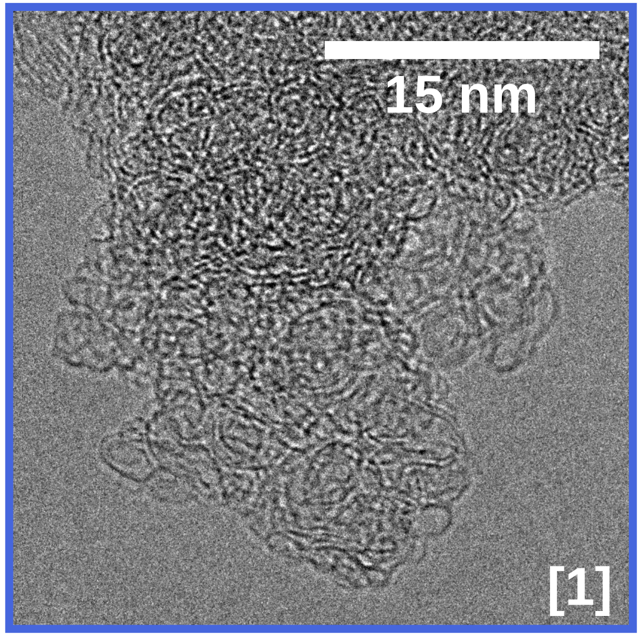
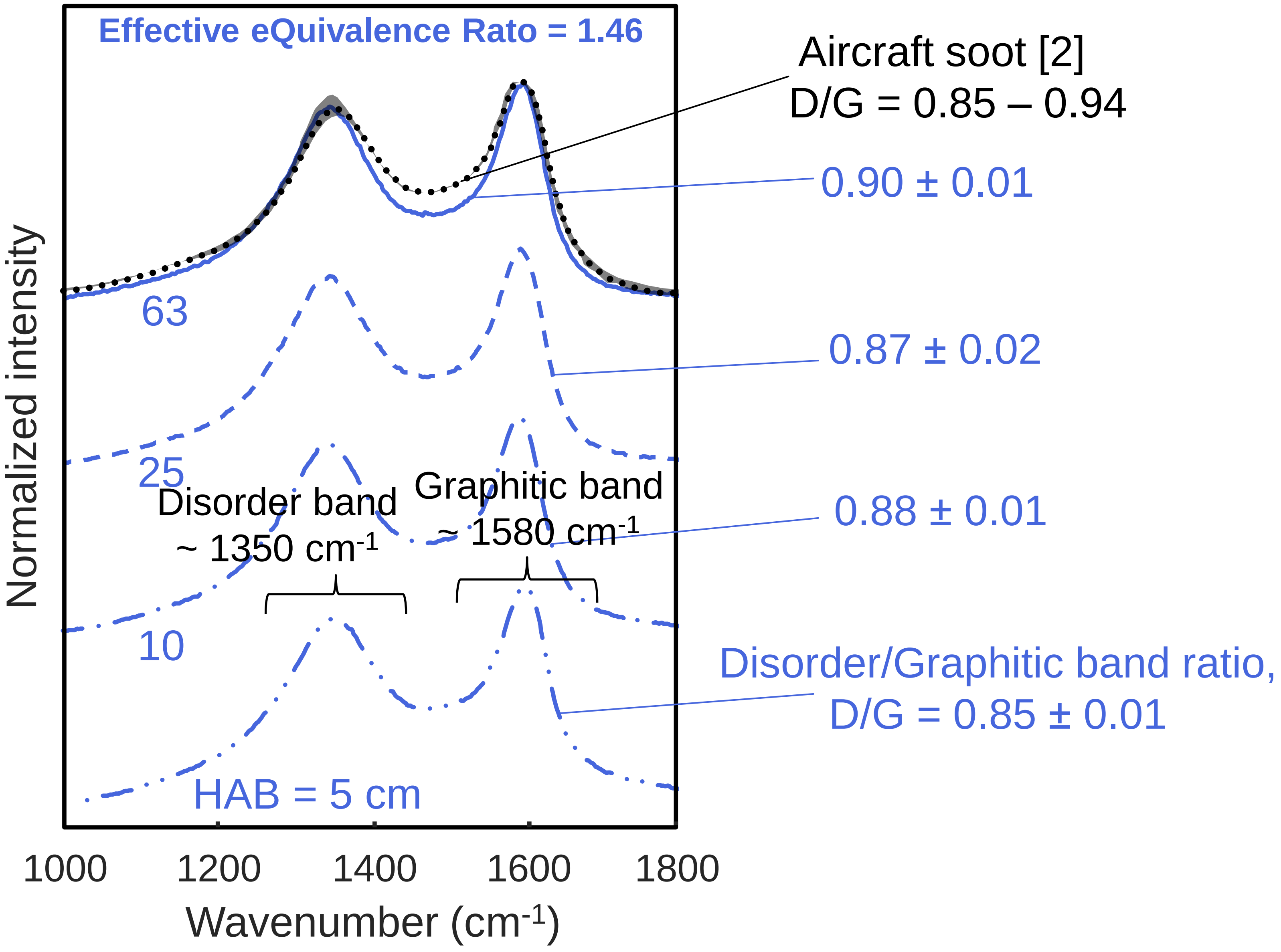
[2] G.A. Kelesidis, E. Goudeli, S.E. Pratsinis (2017) *Proc. Combust. Inst.* 36, 29-50.
[3] G.A. Kelesidis, E. Goudeli, S.E. Pratsinis (2017) *Carbon.* 121, 527-535.

Raman vs Height Above the Burner (HAB)

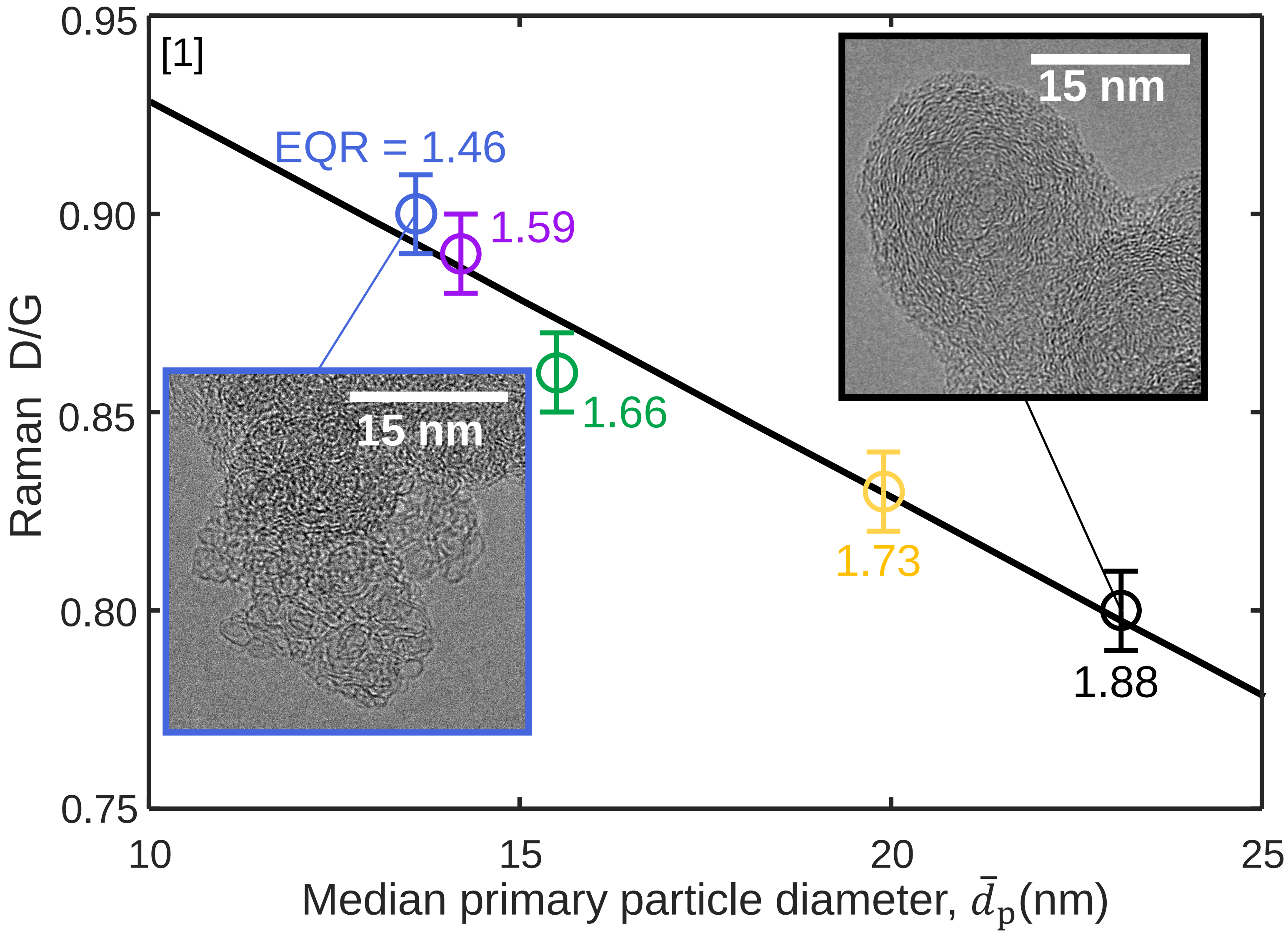




$$EQR = \frac{\left(\frac{Fuel}{Air}\right)_{Actual}}{\left(\frac{Fuel}{Air}\right)_{Stoichiometric}}$$

[1] U. Trivanovic, M. Pereira Martins, S. Benz, G.A. Kelesidis, S.E. Pratsinis (2023) *Fuel.* 342, 127864.
[2] P. Parent, C. Laffon, I. Marhaba, D. Ferry, T.Z. Regier, I.K. Ortega, B. Chazallon, Y. Carpentier, C. Forsca (2016) *Carbon.* 101, 86 – 100

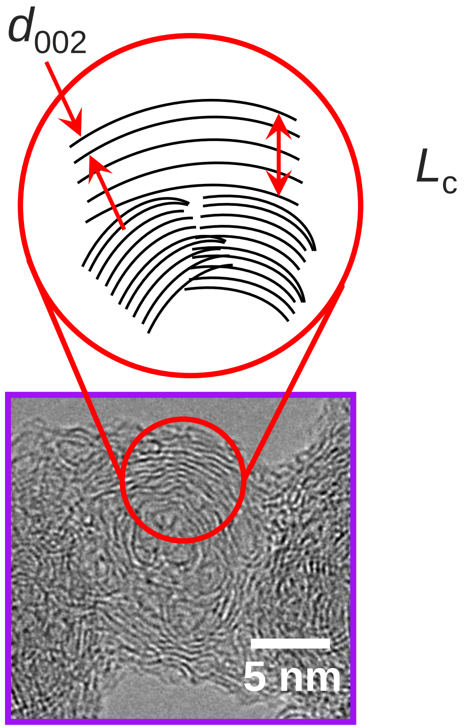
Raman D/G ratio vs primary particle diameter

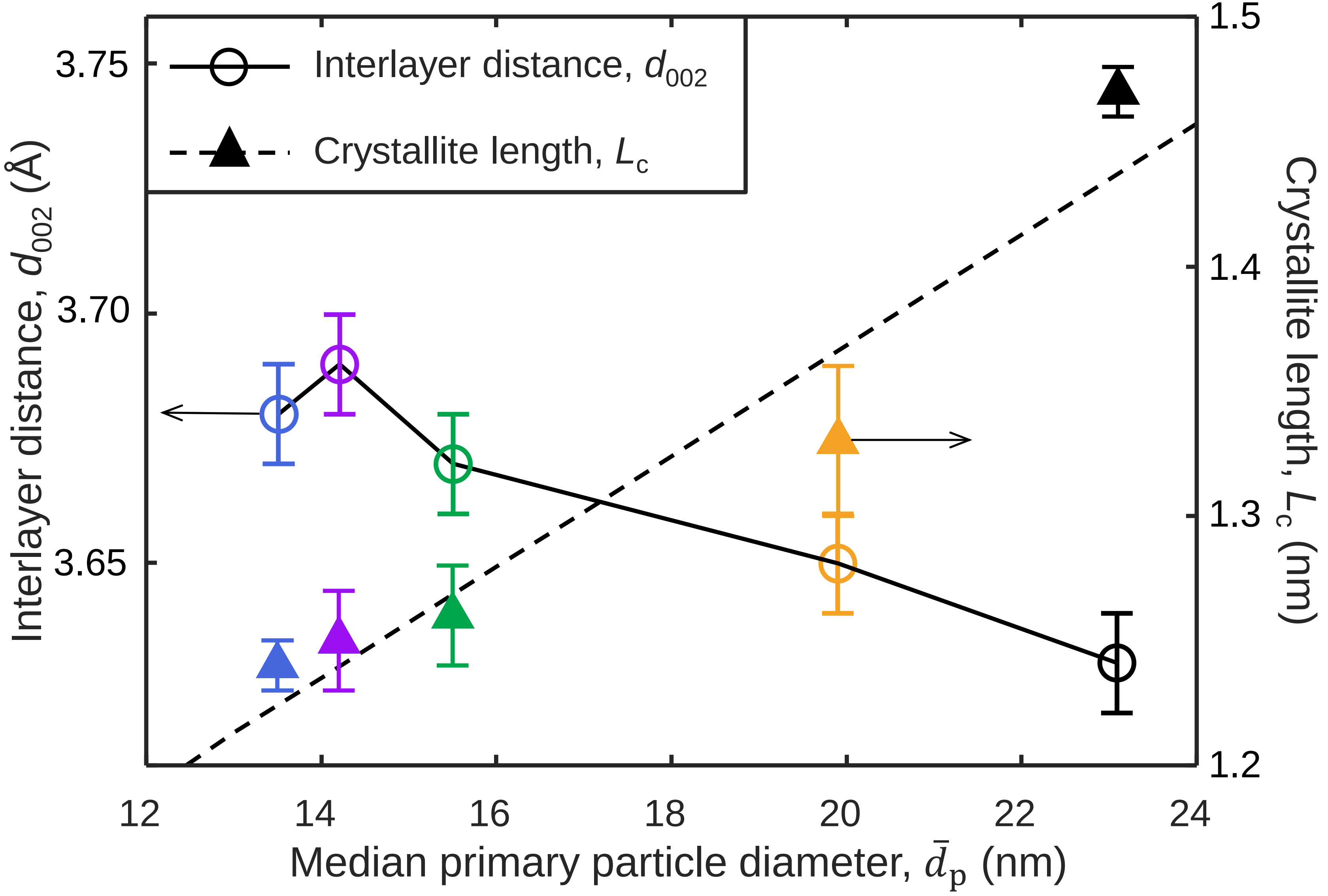


In agreement with size-selected soot from an inverted burner [2] and a gas flare [3].

[1] U. Trivanovic, M. Pereira Martins, S. Benz, G.A. Kelesidis, S.E. Pratsinis (2023) *Fuel.* 342, 127864.
[2] A. Baldelli, S.N. Rogak (2019) *Atmos. Meas. Tech.* 12, 4339 - 4346
[3] U. Trivanovic, T.A. Sipkens, M. Kazemimanesh, A. Baldelli, A.M. Jefferson, B.M. Conrad, M.R. Johnson, J.C. Corbin, J.S. Olfert, S.N. Rogak (2020) *Fuel 279*, 118478

Crystallite size vs primary particle diameter





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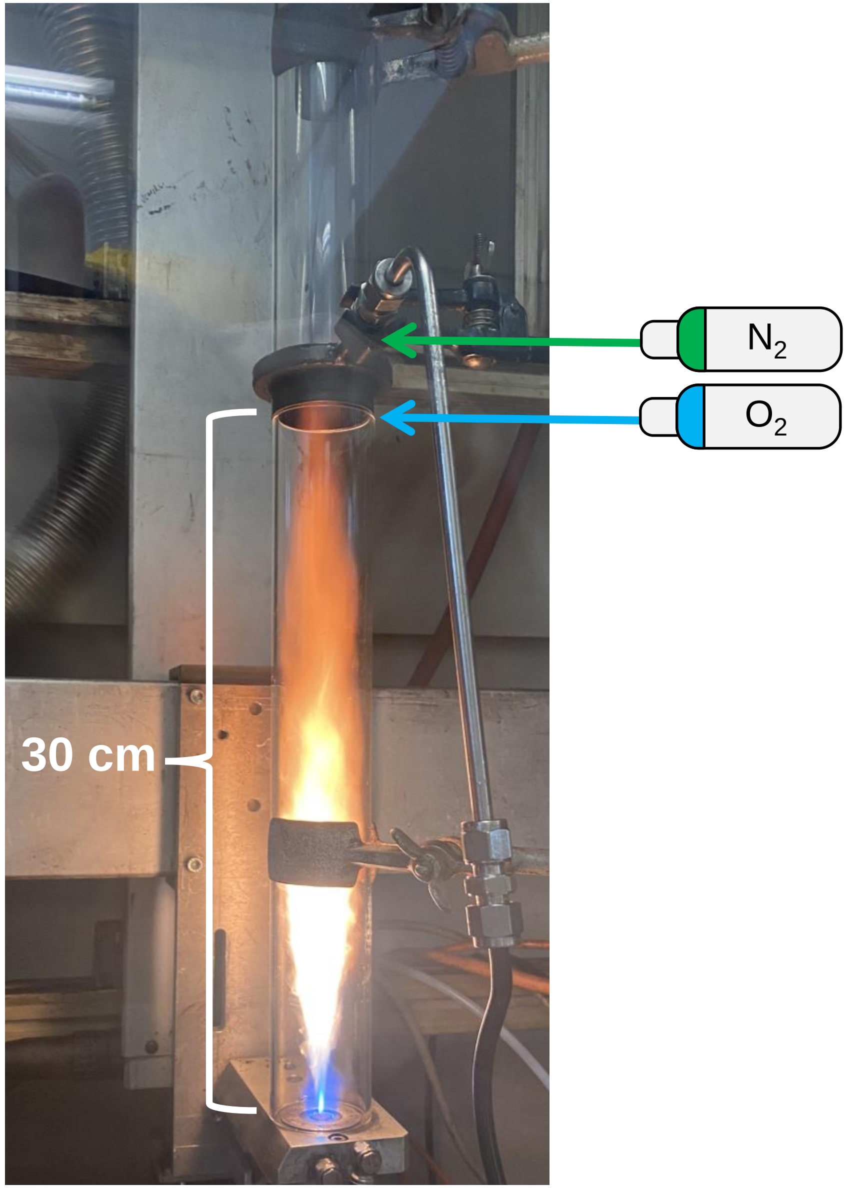
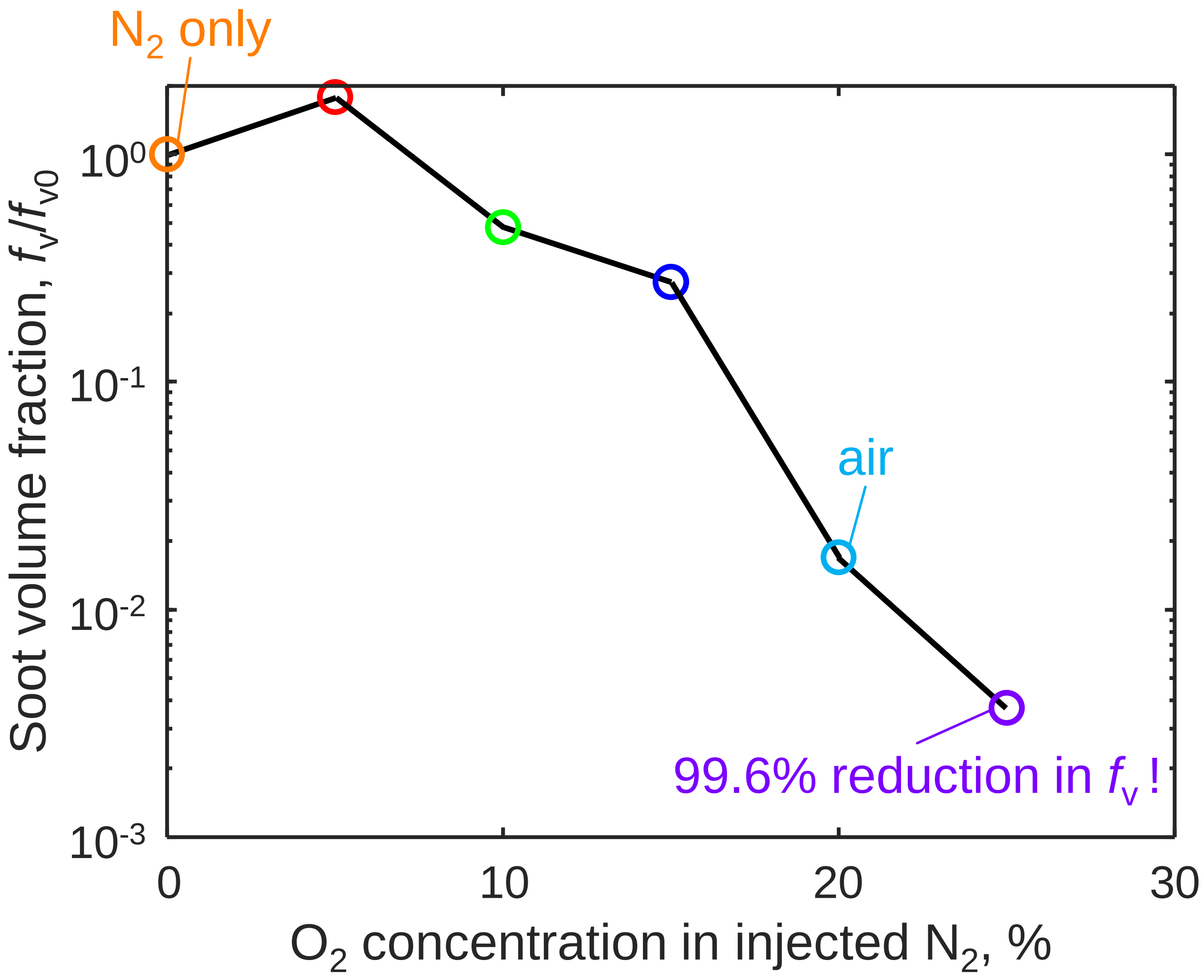
Reducing aircraft soot emissions

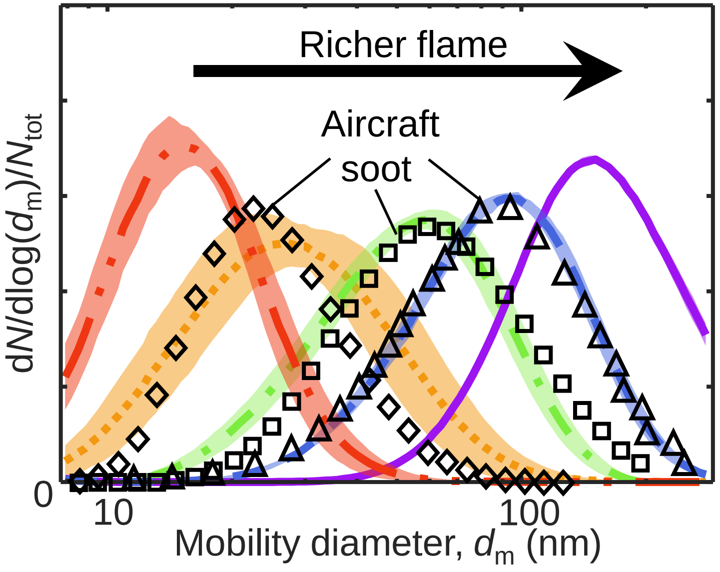


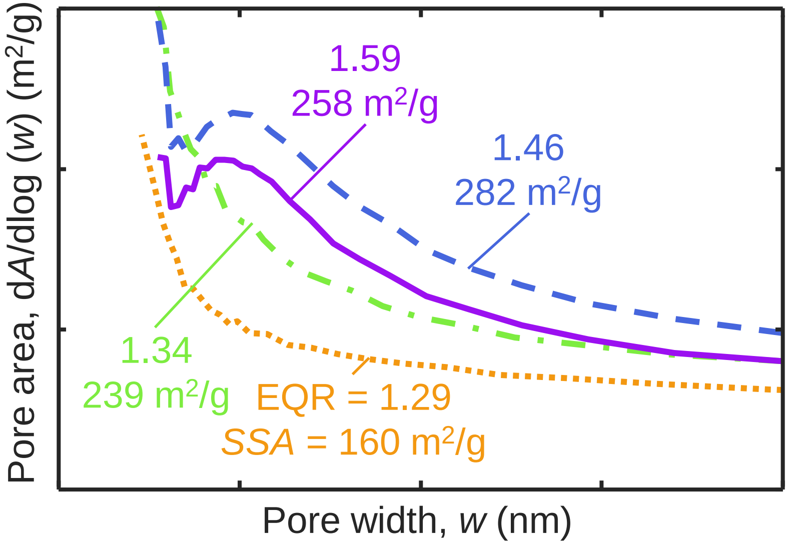


G.A. Kelesidis, A. Nagarkar, U. Trivanovic, S.E. Pratsinis (2023) *Environ. Sci. Technol.* Just Accepted.

Conclusions

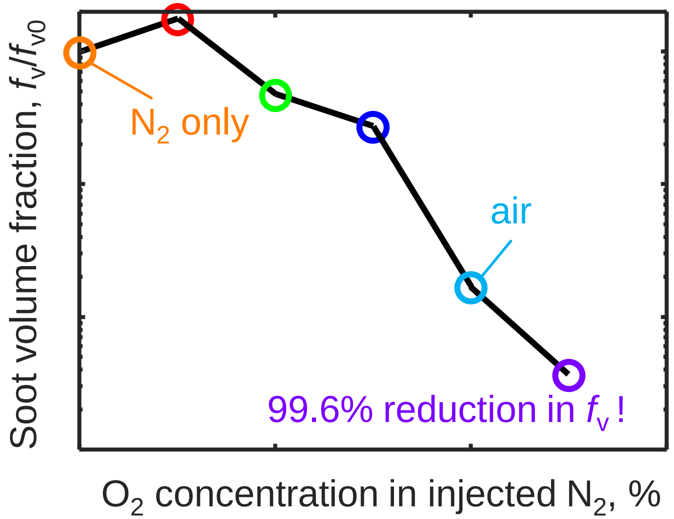
- Relatively large quantities of aircraft-like soot are generated by enclosed spray combustion (ESC)





- This allows for example determination of the specific surface area (SSA) showing that such soot is largely non-porous

- Injection of O_2 can nearly eliminate soot emissions



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Thank you for listening

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